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Sustainability at the Local Scale: Defining Highly Aggregated Indices for Assessing Environmental Performance. The Province of Reggio Emilia (Italy) as a Case Study

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ABSTRACT / In order to achieve improved sustainability, local authorities need to use tools that adequately describe and synthesize environmental information. This article illustrates a methodological approach that organizes a wide suite of environmental indicators into few aggregated indices, making use of correlation, principal component analysis, and fuzzy sets. Furthermore, a weighting system, which includes stakeholders' priorities and ambitions, is applied. As a case study, the described methodology is applied to the Reggio Emilia Province in Italy, by considering environmental information from 45 municipalities. Principal component analysis is used to condense an initial set of 19 indicators into 6 fundamental dimensions that highlight patterns of environmental conditions at the provincial scale. These dimensions are further aggregated in two indices of environmental performance through fuzzy sets. The simple form of these indices makes them particularly suitable for public communication, as they condensate a wide set of heterogeneous indicators. The main outcomes of the analysis and the potential applications of the method are discussed.

Agenda 21 emphasizes the role of local authorities as a pivotal element in the transition towards sustainability (Bosworth 1993; ICLEI 1992). Key aspects in this process are the collection of information concerning the state of the environment and its integration at the various levels of governance to highlight useful patterns for policy planning. In addition, given the importance that Agenda 21 assigns to public participation in environmental decision-making, environmental information must be processed in such a way that facilitates dissemination to nonexperts (ICLEI 1997).

In Italy, municipalities and provinces are the base of the administrative hierarchy. Whereas the latter define general trajectories for development, the former must accordingly set up specific policies. Therefore, provincial authorities need a comprehensive view of municipalities' concerns and priorities, but this is only possible if the municipalities provide enough information about the state of their environment. Three issues are thus of particular relevance: the quality of the information provided by the municipalities, the way it can be synthesized to highlight patterns of environmental performance, and the dissemination of this information to the public.

KEY WORDS: Environmental quality; Fuzzy sets; Indicators; Local planning; Principal component analysis; Sustainability.

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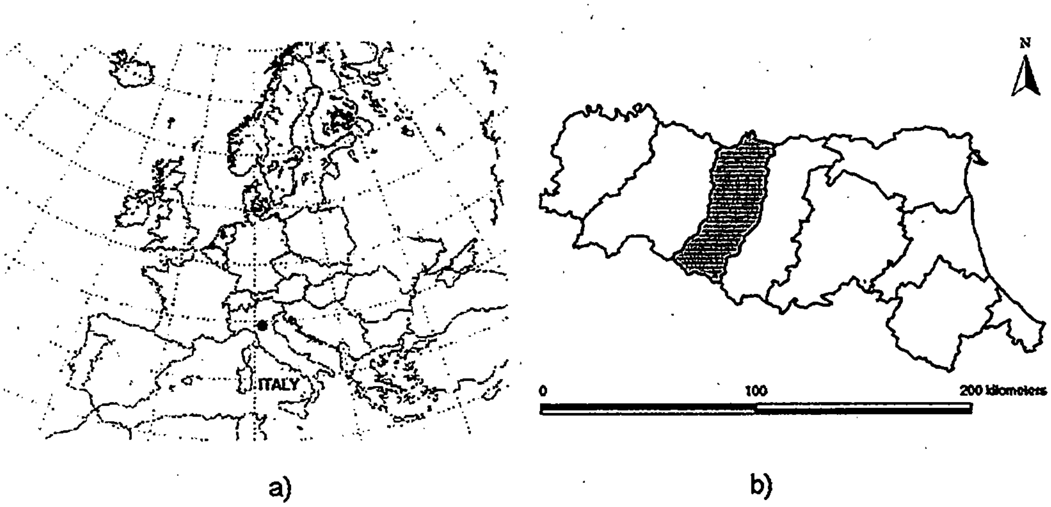
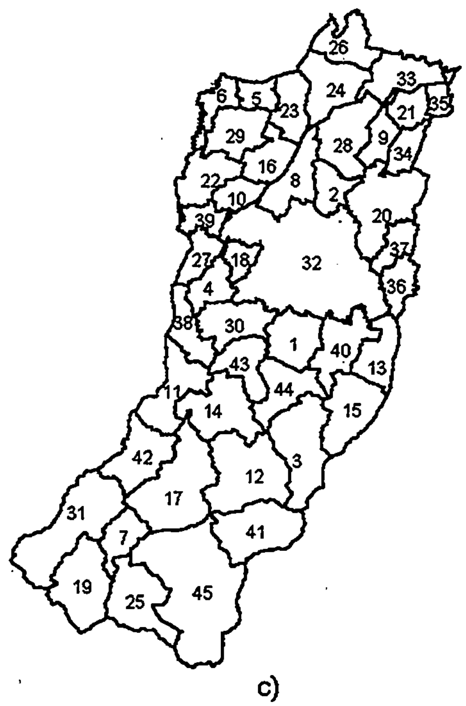
In Italy, there is currently no common environmental database for municipalities within the same province. The only existing initiative was launched in 1997 by the non-governmental organization "Legambiente." This initiative, named "Ecopaese," was designed to document environmental conditions in the municipalities of the province of Reggio Emilia (Figure 1). The study produced a ranking of environmental performances to identify priorities for action at the municipal level (Ferrarini and others 2001).

In the present study, the Legambiente data from the year 2000 was used to synthesize information from each municipality in the search for patterns of environmental quality. This objective has been achieved using a step-by-step aggregation procedure that makes use of (1) Pearson's correlation, to eliminate redundancy in the original dataset, (2) principal component analysis, to reduce the dimensionality of the original database and identify a parsimonious set of indices representative of provincial tendencies, and (3) fuzzy sets, to





ID	Municipality	ID	Municipality
1	ALBINEA	24	GUASTALLA
2	BAGNOLO IN PIANO	25	LIGONCHIO
3	BAISO	26	LUZZARA
4	BIBBIANO	27	MONTECCHIO EMILIA
5	BORETTO	28	NOVELLARA
6	BRESCELLO	29	POVIGLIO
7	BUSANA	30	QUATTRO CASTELLA
8	CADELBOSCO DI SOPRA	31	RAMISETO
9	CAMPAGNOLA EMILIA	32	REGGIO EMILIA
10	CAMPEGINE	33	REGGIOLO
11	CANOSSA	34	RIO SALICETO
12	CARPINETI	35	ROLO
13	CASALGRANDE	36	RUBIERA
14	CASINA	37	S.MARTINO IN RIO
15	CASTELLARANO	38	S.POLO D'ENZA
16	CASTELNUOVO DI SOTTO	39	SANT'ILARIO D'ENZA
17	CASTELNUOVO NE MONTI	40	SCANDIANO
18	CAVRIAGO	41	TOANO
19	COLLAGNA	42	VETTO
20	CORREGGIO	43	VEZZANO SUL CROSTOLO
21	FABBRICO	44	VIANO
22	GATTATICO	45	VILLA MINOZZO
23	GUALTIERI		

d)

Figure 1. Location of the study area in the European context (a); the Reggio Emilia province within the Emilia Romagna region (b); administrative boundaries of all municipalities in the Reggio Emilia province (c); table showing municipality names and their identifiers (d).

create a synthetic index of low and high environmental performance. The main features and outcomes of this study are presented and discussed in this article.

Study Area

The province of Reggio Emilia (henceforth RE) is located in northern Italy, within the Emilia Romagna region (see Figure 1). It extends over about 2292.9 km^2 and sustains a population of 438,500 inhabitants. The province can be subdivided into three parts, based on topography. Figure 2 shows the elevation and population density for the 45 municipalities.

The southern part is mountainous (Northern Apennines) and comprises 10 municipalities (M7, M12, M14, M16, M19, M25, M31, M41, M42, and M45). The central part is hilly and hosts nine municipalities (M1, M3, M4, M11, M15, M30, M39, M43, and M44). The remaining municipalities are in the northern, flat part of the province (Po River plain), in which agri-

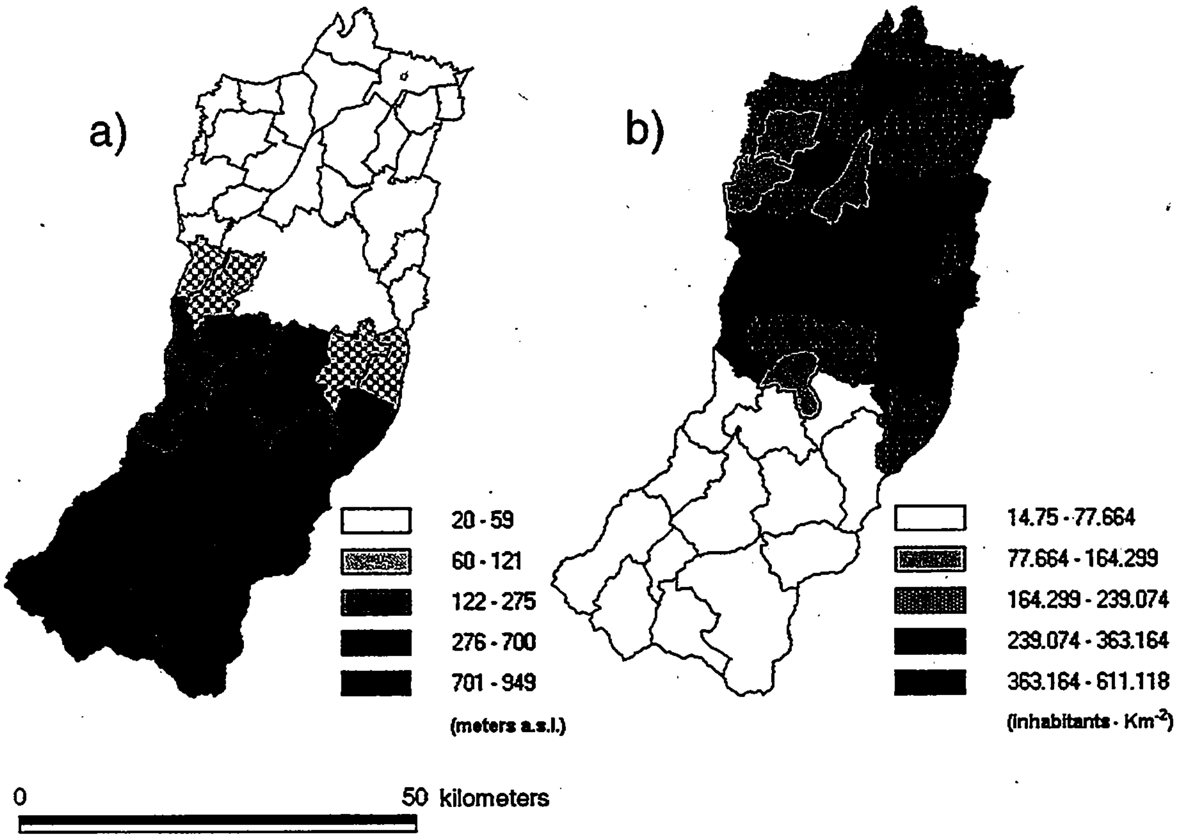


Figure 2. Maps representing elevation of municipalities, meters a.s.l.(a); population density (inhabitants per km^2) for the 45 municipalities of the Reggio Emilia province (b).

culture is the main economic activity. Industrial activity is mostly concentrated in the territory of five municipalities in the eastern part of the province: Casalgrande (M13), Castellarano (M15), Rubiera (M36), Scandiano (M40), and Viano (M44). This area accounts for most of the ceramic tile production of Italy. Food industry is also important (25,000 employees), and more than 20,000 people work in mechanical industries (Anceschi 1995). In the mountainous area, tourism is a considerable source of income. In this part of the province, a National Park (the Apennine Park) has been recently established. Wetlands along the Po River, although of limited extent, are important because of the presence of many species of birds living in typical biotopes (Devillers and Devillers-Terschuren 1993).

Methods

Data Collection

In general, environmental data are selected within a few broad categories, the most common of which are air pollution, climate change, biodiversity, resource exploitation, urban problems, waste production, water pollution, population, health, and disease (OECD 1993; Eurostat 1999). These categories and the parameters that they comprise can vary with assessment scale (planetary, regional, national, local) and environmental context (e.g., city, countryside, or coastal areas) (Palmer and Conlin 1997; Bossel 1999; Berrini and others 2000). For example, detecting variations of CO_2 concentration appears meaningless at the local scale but of critical importance at the global scale. In addition, when investigating the smallest administrative units, reliable measures for certain indicators are often lacking. This is mainly because of uncoordinated monitoring campaigns and lack of expertise in data handling. Due to these intrinsic constraints, metrics of the following categories are used in this study: resource consumption, water quality, air quality, waste management, administrative, and socio-economic factors. Table 1 provides the list of indicators for each category and their units.

Population size (inhabitants per km^2) indicates the generic pressure that is exerted over the environment. Water use (per capita m^3 of potable water) and per capita consumption of electric energy (kWh) were

Table 1. Data used in this study. Each category is made of several metrics (indicators) whose unit is also given. All data refer to year 2000

Category	Metric	Unit
Resource consumption	Water consumption (I1)	Consumption of potable water (liters per capita)
	Energy consumption 1 (I2)	Consumption of electricity (kWh per capita) for civil use
	Energy consumption 2 (I2′)	Consumption of electricity (kWh per capita) for industrial use
Water quality	Nitrates (I3)	Mean annual concentration of nitrates (mg/L)
	Wastewater treatment 1 (I4)	Fraction of the total population that is served by secondary and tertiary treatment
	Wastewater treatment 2 (I4′)	Fraction of the population connected with the sewer system that is served by secondary and tertiary treatment
	Farming (I5)	Tons of pigs and cattle per km^2
Air quality	Discharges in atmosphere (I6)	Number of industries discharging in the atmosphere per km^2
	Traffic 1 (I7)	Per capita number of vehicles
	Traffic 2 (I7′)	Per capita number of cars
Waste	Waste production (I8)	Per capita kg of waste
	Recycling potential (I9)	Quantity of unmixed urban waste (kg per capita)
Administrative issues	Population (I10)	Inhabitants per km^2
	Environmental expenditure (I11)	Municipal budget for environmental initiatives
	Environmental concern (I12)	Number of environmental offices and initiatives in favor of the environment taken by the local administration
Social issues	Age index (I13)	(Inhabitants over 65 aged /inhabitants under 14 aged) 100
	Net migration (I14)	Immigrants and emigrants/yearly average population
Economic issues	Real estates (I15)	Per capita real estates
	Taxable incomes (I16)	Per capita incomes

chosen to quantify resource depletion. Electric consumption might seem anomalous because it does not measure local resource depletion. We decided to include it in the list because the Italian legislation has recently introduced new market-based criteria for the production and distribution of electric energy. According to the new rules, to satisfy the high energy requirements of the industrial compartment (driven by ceramic tile production, one of the most productive in the whole world) at the lowest possible cost, new power plants will be operating in the provincial territory. In all likelihood, they will satisfy completely the local energy demand through special agreements between producers and the local agency in charge of distributing energy to the civil sector.

Several potable water parameters, including heavy metals, ammonia, organic compounds, and pesticides, were not included in the list of indicators, as they were absent in all of the municipalities. Nitrates (annual mean in mg/L) varied considerably among municipalities but never exceeded legal limits.

Available information about air pollution did not cover the entire province, as only 6 municipalities out of 45 had control points. The per capita number of cars and vehicles and the number of industries discharging in the atmosphere were used as proxies for air pollution. The number of vehicles also indicates the pressure due to traffic congestion. Agriculture is an important economic activity in the province of RE, but can also cause severe water pollution problems. The number of pigs and cattle (tons/km^2) present in every municipality was used to estimate nonpoint water pollution. Nontreated wastewater represents one of the most pressing problems at the urban level, and the percentage of inhabitant served by secondary or tertiary treatment plants was included to provide an estimate.

Two indicators relate to waste production: total amount produced per capita and quantity of waste collected in separate form (paper, glass, organic material) as the result of source separation. The first indicator is a true measure of environmental pressure, whereas the second is important because municipalities, by law, have to collect waste in separate form to promote recycling, an important component of sustainability. Because recycling is organized and managed by companies that operate at a regional scale, efficiency of recycling at the municipal level could not be calculated; instead, what each municipality collects in separate form, a measure of recycling potential, appears in the list.

Expenditure to improve environmental conditions and the number of offices or initiatives devoted to solve environmental problems or promote public environmental awareness are important indicators of the environmental attitude of each municipality; as such, they were included in the list.

Although the survey was devised to describe essentially the baseline environmental conditions, the addition of social and economic metrics was deemed necessary. As municipal revenue heavily depends on taxation, an economically prosperous municipality might provide more resources to its local government, with potential beneficial repercussions upon environmental policies. To take this into account, real estate and taxable income were added to the indicators list. Two social indicators complete the list: age index and net migration. These measures were chosen in the understanding that a well-balanced population is a prerequisite for economic prosperity, which, in turn, affects environmental initiatives, as discussed earlier.

Because indicators are central to the decision-making process (Beinat and Nijkamp 1998), one should always consider whether the retained measures are appropriate. Selecting these indicators was intricate because only parameters measured in all municipalities could be used (Knut and Saebo 1993). Despite such constraints, the retained list includes several indicators that are often employed in sustainability studies (Hardi and Pinter 1994).

Statistical Analysis

Correlation and Principal Component Analysis. Redundant information was first inspected by the Pearson's correlation using the statistical package SPSS 9.0. After eliminating redundant information, the new dataset was analyzed by principal component analysis (PCA) in search of meaningful underlying variables describing emergent "*collective*" phenomena. These new variables $\boldsymbol{Y_i}$ are weighted linear combinations of the p original ones (expressed as deviation $\boldsymbol{X_i}$ from the mean value) and represent gradients of maximum variation within the dataset. They take the form

$$Y_i = a_{i1} \cdot X_1 + a_{i2} \cdot X_2 + a_{ij} \cdot X_j \ldots + a_{1p} \cdot X_p \qquad (1)$$

The $\boldsymbol{Y_i}$ components are orthogonal (uncorrelated) between one another. Geometrically, principal components can be viewed as projections through the clouds of sample points at orientations that maximize variations along each axis. Principal components are not derived directly from the original data matrix; instead, the covariance matrix $\vec{C}$ or its standardized form, the correlation matrix, is used. They both are $\boldsymbol{p \times p}$ symmetrical matrices in which the diagonal coefficients estimate internal association of original variables; the off-diagonal elements describe the relationship between each pair of variables. In matrix $\vec{C}$, diagonal coefficients are variances and off-diagonals are covariance.

Because the indicators are not expressed in the same units, a PCA based on the covariance matrix would be inappropriate. Indicators were thus standardized (i.e., transformed into variables with zero mean and unit variance). After normalization, the indicators were weighted in relation to the different priorities that people attached to the issues these variables measure. We used weights derived from a priority problem posed to local administrators (Ferrarini and others 2001). The original standardized data were then transformed using the array of weights, as expressed by

$$X_s^* = X_s \cdot (\omega_s)^{1/2} \qquad (2)$$

where $\boldsymbol{X_s}$ is the sth standardized indicator, and ω_s is its associated weight. In order to build the weighted covariance matrix, we corrected the weights by a factor of ½ (Greenacre and Blasius 1994). The matrix coefficients have the form

$$\frac{COV(X_1^* X_2^*)}{(\omega_1)^{1/2}(\omega_2)^{1/2}} \qquad (3)$$

where ω_1 and ω_2 are the weights assigned to variables X_1^* and X_2^*, respectively.

Computationally, the procedure is an eigen analysis problem, which requires solving the characteristic equation

$$\left|\vec{C^*} - \vec{\lambda}\,\vec{I}\right| = 0 \qquad (4)$$

in which $\vec{C^*}$ is the standardized covariance matrix and $\vec{I}$ is the identity matrix. The outcome is the λ vector of eigenvalues, which measures the variability of the original variables with respect to the dimension specified by each principal component. The eigenvalues are ordered from the largest to the smallest, and each represents a dimension that explains part of the variability in the original data. The component with the largest eigenvalue captures and explains the majority of the variability in the data. The second eigenvalue measures the variance along the second principal component and quantifies the maximum variability in a direction that is orthogonal to the first principal component.

To obtain an acceptable "compression ratio," the number of principal components must be limited.

Generally, an adequate number of components should account for at least 70% of the original variance, but this threshold can vary as a function of the number of original variables (Jackson 1993; Zani 2000).

The relationship between original variables and principal components can be obtained by solving

$$\left(\vec{C^*} - \lambda_i \vec{I}\right)\vec{a_i} = 0 \qquad (5)$$

The coefficients of any eigenvector $\vec{a_i}$ are directly proportional to the correlation between the original variables and the principal components. In other words, they weight the contribution of the original variable in the principal components and provide clues to interpret the meaning of the emerging latent dimension and their relationship with the original variables.

Fuzzy Approach. A fuzzy approach (Zadeh 1965) is used in the final step of the aggregation process to create a unique index of environmental performance. The use of fuzzy sets is an organized method that allows dealing with data imprecision or ambiguities implicit in decision rules (Zimmermann and others 1984). These problems are very frequent in environmental contexts, where assessments based on imprecise measures are often required (i.e., bad or good quality, acceptability of certain impacts, and so forth).

Because a fuzzy set is a set to which objects belong to different degrees, called *grades of membership*, we considered environmental performance of the municipalities as belonging to two possible sets: one of good and one of bad performance. In general any element x_i that is part of a larger set X belongs to the subset K according to its membership function $\mu_K : X \rightarrow [0,1]$, where $\mu_K(x)$ is interpreted as the degree of membership in fuzzy set K for $x_i \in X$.

The membership function associates to every element x_i a value between 0 and 1: The latter expresses complete membership for x_i to the fuzzy set K and the former assigns no membership to K. Intermediate values define partial memberships. To establish this, grade rules of membership must be defined. As stated earlier, in this work two fuzzy sets have been conceived: They are called "good" and "bad" environmental performance. The measurable aspects used to assign every municipality its membership in the two fuzzy sets were their behavior in relation to the fundamental dimensions of environmental quality obtained by the principal component analysis. Such behavior was measured by scores, obtained by calculating the selected principal components for each municipality (Jackson 1991). To assign a membership to each municipality, we used the quantile method of classification, in which values are divided equally among classes, based on rank. In practice, the qth quantile of a dataset is defined as that value where a q fraction of the data is below that value and a $1-q$ fraction of the data is above that value. The threshold value q is not a rigid criterion, but it has been successfully applied in previous studies (Zani 1996). Choosing a quantile order also depends on the importance we attribute to situations far from the mean behavior (e.g., deciles provide information related to situations more distant from the mean than quintiles do).

In this study, for each principal component the first 20% of the scores were assigned to the "good" performance set, whereas the last 20% of the scores in the rank were assigned to the "bad" performance set (quintile threshold). To summarize, the rules of membership for every territorial unit i in relation with each component c are

$Z_c(i) = 1$ if i ($i = 1,\ldots,45$) scores in the best (in the case of the high performance set) and worst (low performance set) 20% of the values for the given component c; and

$Z_c(i) = 0$ if i ($i = 1,\ldots,45$) scores in the other 80% of the cases for both sets.

Finally, given this rule of selection for each component, the overall membership of a territorial unit i for both sets was calculated as

$$\mu_A(i) = \frac{1}{n} \cdot \sum_{c=1}^{n} Z_c(i) \quad i = 1, \ldots, 45 \qquad (6)$$

Complete membership to the high-performance set is obtained when the ith territorial unit receives a value of 1 for all the components, whereas a complete membership to the low-performance set is assigned if all the components of a certain municipality receive zero values.

A GIS package (Arcview 3.1) has been used to represent the results of both PCA and fuzzy sets to make their interpretation easier.

Results

The initial set of indicators (see Table 1) was first tested by Pearson's correlation in search for redundant information. The results of this analysis are given in Table 2. The table contains 65 pairs of indicators for which correlation is significant (for a sample of 45 units, a correlation coefficient higher than 0.4 is accepted as a sign of tendency). We considered that indicators bring redundant information if two conditions are met: They are significantly correlated and they measure similar phenomena (Zani 2000). For example, taxable income (I16) and energy consump-

Table 2. Pearson correlation coefficients (r_{xy}) calculated for all possible pairs of indicators listed in Table 1. Each cell provides the value of r_{xy} and the related two-tails significance level. Symbols: *0.05 significance level. **0.01 significance level.

	I1	I2	I2'	I3	I4	I4'	I5	I6	I7	I7'	I8	I9	I10	I11	I12	I13	I14	I15	I16
I1																			
I2	0.632**																		
	0.000																		
I2'	−0.109	0.303*																	
	0.477	0.043																	
I3	−0.505**	0.705**	−0.132																
	0.000	0.000	0.389																
I4	−0.265	0.464**	0.076	0.549**															
	0.079	0.001	0.620	0.000															
I4'	−0.237	0.596**	0.111	0.531**	0.855**														
	0.118	0.000	0.468	0.000	0.000														
I5	−0.517**	0.679**	0.075	0.514**	0.282	0.383**													
	0.000	0.000	0.625	0.000	0.061	0.009													
I6	−0.160	0.496**	0.513**	0.413**	0.340*	0.336*	0.414**												
	0.294	0.001	0.000	0.005	0.022	0.024	0.005												
I7	0.044	0.427**	0.527**	0.144	0.181	0.312*	0.278	0.456**											
	0.774	0.003	0.000	0.345	0.235	0.037	0.065	0.002											
I7'	−0.045	0.591**	0.474**	0.319*	0.165	0.353*	0.329*	0.469**	0.845*										
	0.769	0.000	0.001	0.033	0.278	0.017	0.027	0.001	0.000										
I8	−0.511**	0.334*	0.012	0.306*	0.486**	0.342*	0.483**	0.282	−0.021	−0.073									
	0.000	0.025	0.937	0.041	0.001	0.022	0.001	0.061	0.890	0.632									
I9	−0.362*	0.599**	0.087	0.598**	0.412**	0.408**	0.398**	0.410**	0.139	0.263	0.419**								
	0.014	0.000	0.570	0.000	0.005	0.005	0.007	0.005	0.362	0.080	0.004								
I10	−0.301*	0.627**	0.199	0.611**	0.467**	0.422**	0.574**	0.709**	0.492**	0.556**	0.442**	0.503**							
	0.045	0.000	0.190	0.000	0.001	0.004	0.000	0.000	0.001	0.000	0.002	0.000							
I11	−0.021	−0.332	0.013	−0.251	0.010	−0.182	−0.168	−0.192	−0.210	−0.337	0.133	−0.122	−0.267						
	0.891	0.026	0.935	0.096	0.947	0.231	0.269	0.207	−0.166	0.024	0.384	0.424	0.076						
I12	−0.545*	0.623**	0.204	0.508**	0.423**	0.457**	0.529**	0.360*	0.261	0.285	0.504**	0.593**	0.502**	−0.083					
	0.000	0.000	0.179	0.000	0.004	0.002	0.000	0.015	0.083	0.058	0.000	0.000	0.000	0.589					
I13	0.443*	−0.719	−0.394**	−0.439**	−0.149	−0.381**	−0.426**	−0.434*	−0.554*	−0.702**	−0.054	−0.358*	−0.481**	0.302*	−0.525**				
	0.002	0.000	0.007	0.003	0.327	0.010	0.004	0.003	0.000	0.000	0.723	0.016	0.001	0.044	0.000				
I14	−0.482*	0.556**	0.393**	0.303*	0.250	0.410**	0.404**	0.463*	0.397**	0.368*	0.283	0.372*	0.432**	−0.109	0.506**	−0.693*			
	0.001	0.000	0.008	0.043	0.098	0.005	0.006	0.001	0.007	0.013	0.059	0.012	0.003	0.478	0.000	0.000			
I15	−0.173	0.349*	0.524**	0.246	0.516**	0.368**	0.314*	0.584*	0.352*	0.309*	0.547**	0.336*	0.511**	0.270	0.303*	−0.117	0.264		
	0.256	0.019	0.000	0.104	0.000	0.013	0.036	0.000	0.018	0.039	0.000	0.024	0.000	0.073	0.043	0.442	0.080		
I16	−0.259	0.707**	0.367*	0.526**	0.493**	0.534**	0.369*	0.590*	0.567**	0.692**	0.273	0.476**	0.745**	−0.129	0.356*	−0.550**	0.501**	0.572**	
	0.086	0.000	0.013	0.000	0.001	0.000	0.013	0.000	0.000	0.000	0.069	0.001	0.000	0.400	0.017	0.000	0.000	0.000	

Table 3. Groups of indicators used in the principal component analysis and weights that measure their importance as average preference expressed by local administrators on a 1–7 point scale (Ferrarini and others 2001)

Environmental indicators				Social indicators		Economic indicators	
Pressure	Weight	Response	Weight		Weight		Weight
Water consumption (I1)	4.96	Wastewater treatment 1 (I4)	5.76	Age index (I13)	6	Real estate (I15)	6
Energy consumption 1 (I2)	4.62	Recycling potential (I9)	5.85	Net migration (I14)	6	Taxable income (I16)	6
Energy consumption 2 (I2′)	4.62	Environmental expenditure (I11)	5.18				
Nitrates (I3)	5.88	Environmental concern (I12)	5.18				
Discharges in atmosphere (I6)	5.03						
Traffic 1 (I7)	5.12						
Farming (I5)	4.53						
Waste production (I8)	5.85						
Population (I10)	6						

tion for domestic uses (I2) are positively correlated (richer families are more consumption-oriented) but eliminating either one of the two metrics would produce a loss of genuine information, because they measure different phenomena.

As a criterion, we selected pairs of indicators that not only showed a clear significant correlation (>0.8) but also measured similar phenomena: I4-I4′ and I7-I7′. In the former pair, the fraction of the total population served by secondary and tertiary treatment (I4) seemed more representative than I4′. The latter, in fact, would overestimate wastewater facilities, as it does not take into account those families that are not connected to the sewer system and that certainly are not served by treatment plants. Because a significant fraction of air pollution due to traffic is produced by vehicles other than cars, I7 seemed more appropriate than I7′ to estimate air pollution.

Results of correlation provide a preliminary overview of environmental quality patterns at the provincial level. Population density (I10) shows positive significant correlation with energy consumption for domestic use (I2), nitrate concentration (I3), water treatment (I4), farming (I5), discharges in the atmosphere (I6), total number of vehicles (I7), waste production (I8), recycling potential (I9), environmental initiatives (I12), net migration (I13), real estate (I15), and taxable income (I16). It is also negatively correlated with age index (I13). With reference to Figure 2, population density is higher in the northern part of the province, which is flat, and in some municipalities of the hilly area (Nos. 1, 13, 15, 30, 38, and 40, see Figure 1 for correspondence). Almost all indicators that are positively correlated with population density show positive correlation between each other (e.g., I3—nitrate concentration—in relation to I2, I4, I5, I6, I9, I13, and I16). In general, it appears that most environmental pressure concentrates in municipalities located in the lowlands and the nearby hilly areas. Also, these are more effective in terms of recycling potential, environmental awareness, wastewater treatment; moreover, their potential for response appears greater (richer and demographically well-balanced communities).

The age index (I13) is negatively correlated with population density and all of the other indicators positively correlated with it. This suggests that in the mountain district, environmental pressure is less pronounced (lower nitrate concentration in the water, reduced energy consumption, less atmospheric discharges and fewer vehicles, less farming activity). On the other hand, these municipalities show a lower response capability because of lower environmental awareness and weaker recycling potential. Furthermore, they have fewer economic and human resources, as the age structure of their communities is unbalanced in favor of older-age classes (Ferrarini and others 2001).

In flat and hilly municipalities, where agriculture and industry are more developed, water consumption appears lower than in mountainous areas. It is, in fact, negatively correlated with I3, I2, I5, I8, I9 (r_{xy}<0.4), I10 (r_{xy}<0.4), I12, and I14 and shows positive correlation with I13. One would expect water consumption to be more pronounced where population is high and productive activity thrives. This unexpected result can be

Table 4. Principal components obtained for indicators of environmental pressure and eigenvectors associated with the first two components that explain 67% of the variance in the original data

	Comp. 1	Comp. 2	Comp. 3	Comp. 4	Comp. 5	Comp. 6	Comp. 7	Comp. 8	Comp. 9
St. dev.	4.532384	2.589688	2.15031	1.973764	1.444822	1.089435	0.997574	0.743257	0.145426
Prop.Var.	0.505828	0.165137	0.113855	0.095927	0.051402	0.029225	0.024504	0.013603	0.000521
Cumul. Prop.	0.505828	0.670964	0.784819	0.880746	0.932148	0.961372	0.985876	0.999479	1
I1	−0.665	0.390							
I2	0.862	0.016							
I2′	0.247	0.793							
I3	0.776	−0.268							
I5	0.782	−0.151							
I6	0.687	0.602							
I7	0.371	0.541							
I8	0.616	−0.306							
I10	0.837	0.217							

Table 5. Principal components obtained for indicators of environmental response and eigenvectors related to the first two components that explain 74% of the variance in the original data

	Comp. 1	Comp. 2	Comp. 3	Comp. 4
St. dev.	3.279076	2.266894	1.847626	1.474872
Prop. Var.	0.500572	0.239236	0.158925	0.101268
Cumul. Prop.	0.500572	0.739807	0.898732	1
I4	−0.735	−0.278		
I9	−0.850	0.077		
I11	0.157	−0.960		
I12	−0.826	0.002		

Table 6. Principal components obtained for indicators of economic performance and the eigenvectors related to the first components that explain 78% of the variance in the original data

	Comp. 1	Comp. 2
St. dev.	2.93543	1.545118
Prop. Var.	0.783046	0.216954
Cumul. Prop.	0.783046	1
I16	0.868	
I15	0.900	

Table 7. Principal components obtained for social indicators and the eigenvectors related to the first components that explain 84% of the variance in the original data

	Comp. 1	Comp. 2
St. dev.	1.301153	0.554076
Prop. Var.	0.8465	0.1535
Cumul. Prop.	0.8465	1
I13	0.920	
I14	−0.920	

explained by the fact that in mountainous areas, the water distribution system is obsolete and water leak exceeds values measured in the other part of the province.

Energy used for production shows a positive correlation with the number of vehicles, discharge in the atmosphere, net immigration, real estate, and taxable income. The fact that it shows no relation with population density, farming, nitrate concentration in waters, urban waste, recycling potential, and wastewater treatment leads one to conclude that industrial activity is not equally distributed in the northern part of the province. As a matter of fact, I2′ correlates only with metrics that are specific for industrial production, whereas it shows no relationship with more general indicators of environmental pressure. Its nonsignificant correlation with waste production and water treatment deserves further comment. Industries, in fact, neither produce waste that enter the normal cycle of urban wastes nor discharge their waters in the civil

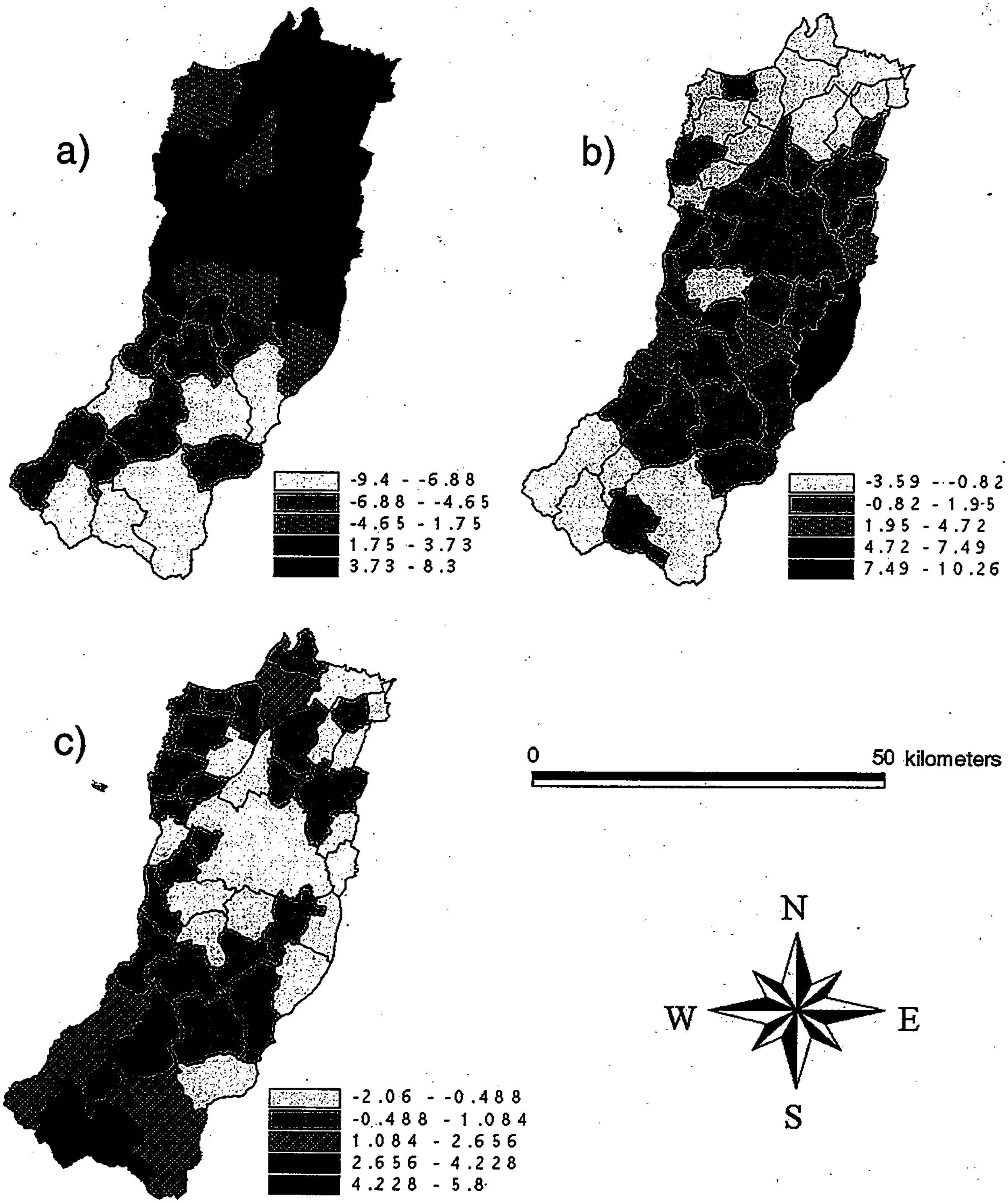


Figure 3. Spatial distribution of the scores related to settlement pressure (a), industrial pressure (b), and incapability of response (c).

sewer system. However, small industries do share the same behaviors, and because large firms, those that are part of the ceramic tile circuit, are located only in certain municipalities (13, 14, 36, 40, and 44), one would expect industrial pressure emerging as a well-defined spatial pattern.

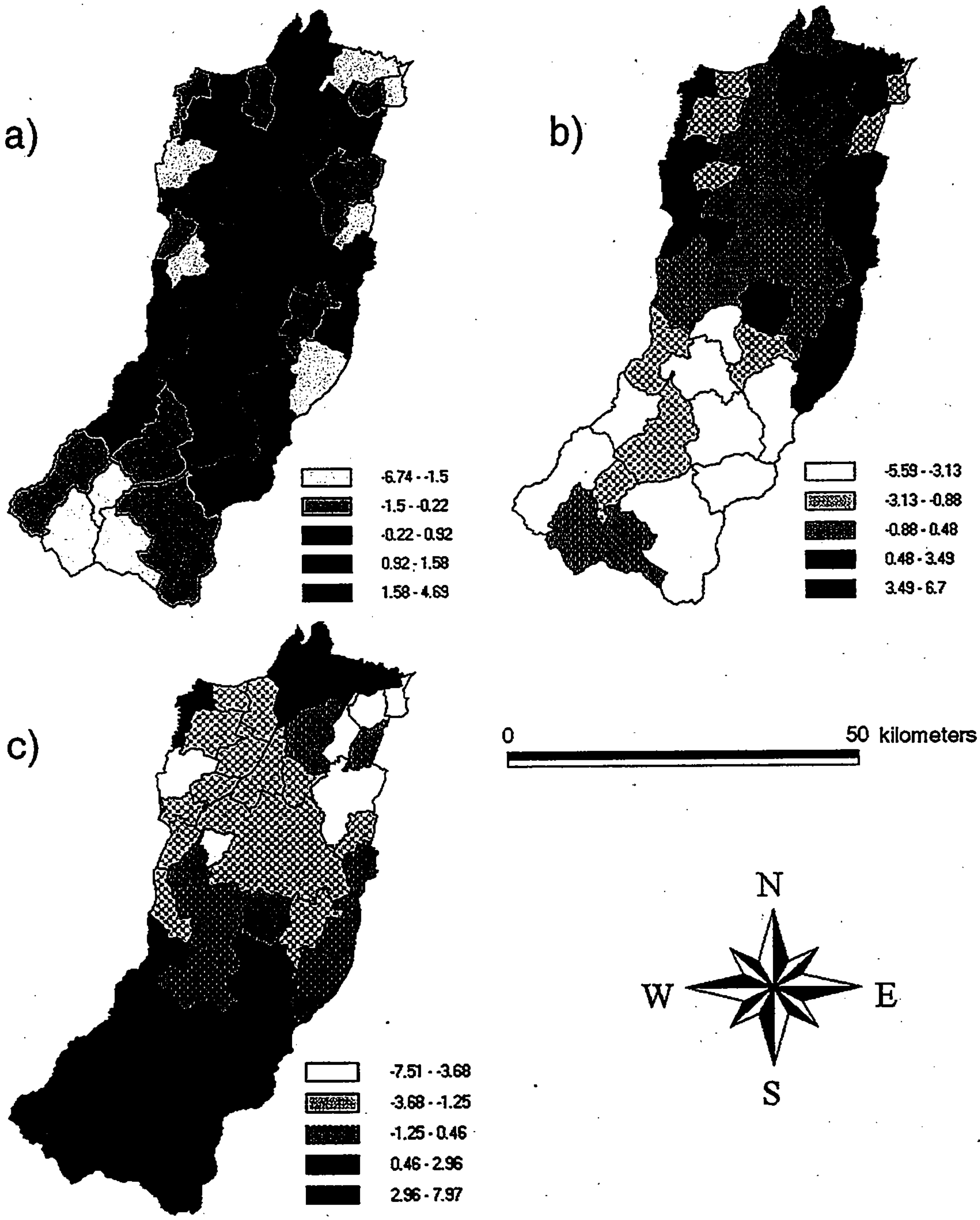


Figure 4. Spatial distribution of the scores related to environmental expenditure (a), economic well-being (b), and unbalanced population (c).

Environmental, social, and economic indicators have been kept separated and environmental indicators further divided into groups: indicators of pressure and indicators of response. Attached to each indicator there is a weight, obtained by averaging preference values provided by local administrators (Ferrarini and others 2001). The scale of preferences, based on a 1 to 7 point scale, was chosen as recommended in the literature (Voogd 1983). The weighting scheme serves the purpose of local inclusion. Environmental surveys provide baseline information to set up environmental policies and programs, which, in turn, are inspired by a vision for the future. Such vision should not be developed without the contribution of people's perception and priorities (Hardi and Zdan 1997). Table 3 shows the various groups of indicators and the associated weights. These groups have been examined through principal component analysis. We adopted this strategy because including all the metrics in a unique PCA scheme produced new emerging dimensions whose meaning is not clearly interpretable, as they mixed in an unintelligible way as economic, environmental, and social factors.

Results of PCA are given in Tables 4–7 and Figures 3 and 4. For each group of indicators a table is presented. It shows the number of components that explain an adequate amount of variance, their standard deviation, their relative and cumulative variance, and the eigenvector associated. For each component, the municipality scores have been summarized in a map, which displays underlying variables describing latent collective phenomena in a spatial context. This, in turn, helps to identify indices patterns at the provincial scale.

Results of the PCA for pressure and response indicators are given in Tables 4 and 5, respectively; maps in Figure 3 show the associated spatial distributions.

The results for social and economic indicators are summarized in Tables 6 and 7, respectively, and the emerging dimensions are spatially displayed in the maps of Figure 4.

The first two components explain an adequate amount of variance in the dataset for environmental pressure (Table 4) and represent interpretable dimensions. The first component shows high positive correlation with indicators I2 (energy consumption for domestic uses), I3 (nitrates in water), I5 (farming), I6 (discharges in atmosphere), I8 (waste production), and I10 (population density). The second component is strongly related with I6 (discharges in atmosphere), I2′ (energy consumption for industrial uses), and I7 (total number of vehicles). These latter indicators are associated with the pressure exerted by production activities; thus, the second component could be considered an index of industrial pressure. On the other hand, the first component seems more related to the generic pressure exerted by human settlements. Maps a and b in Figure 3 display the first and second component values for each municipality, respectively. The settlement pressure index assumes high values in the northern part of the province, where most population concentrates. The index of industrial pressure has maximum values in a restricted area in the eastern part of the province, where the ceramic tile production concentrates, as expected from the previous correlation analysis.

Therefore, at the provincial scale, environmental pressure can be represented by two distinct spatial patterns: one due to settlements (both civil and agricultural) and the other due to industrial activities. Some municipalities are both densely populated and sustain a high level of industrial production; nevertheless, there are cases in which lower industrial pressure is tied with low settlement pressure (mountainous areas). However, there is no complete overlap between these two dimensions of environmental pressure, as clearly displayed by the spatial distribution of the two components.

Water consumption certainly contributes to settlement pressure, but the PCA showed that it is inversely related with this index: Areas in which settlement pressure is lower appear to consume more water.

Within the response indicators group, two components explain 74% of the variance (Table 5). Indicators I4, I9, and I12 show an inverse relation with the first component and I11 shows a significant negative correlation with the second component. Given that I4 (wastewater treatment), I9 (recycling potential), and I12 (environmental concern) measure the capability of facing certain environmental problems, the collective dimension associated with the first component can be interpreted as an index of incapability to offset environmental problems. The distribution of this index (Figure 3c) supports the results of the correlation analysis (Table 2), which indicated how the municipalities in the mountainous areas appear less capable of taking action in response to environmental problems.

The second principal component is only correlated, in a negative way, with the environmental expenditure and appears isolated to other observed phenomena. Furthermore, the spatial distribution of this component (Figure 4, upper left map) does not seem to produce a clear pattern at the provincial scale. This result might depend on the fact that municipalities responded to the environmental expenses queries by calculating an overall amount that included money spent for increasing green areas or for usual maintenance activities. Environmental expenses, as calculated by municipalities, might change from year to year as they respond to fluctuations in the availability of funds. This produces a tendency to spend as much as possible on the short term to get new funds the following year. In this way, long-term projects needed to offset serious environmental problems become secondary to short-sighted, routine maintenance-oriented plans. This

Table 8. Grade of membership of each municipality in the fuzzy set called "good performance"

Municipality	ID	Settlement pressure Z1	Industrial pressure Z2	Incapability for response Z3	Environmental expenditure Z4	Economic well being Z5	Unbalanced population Z6	μA
Albinea	1	0	0	0	0	1	1	0.33
Bagnolo in Piano	2	0	0	1	0	0	0	0.17
Baiso	3	1	0	0	0	0	0	0.17
Bibbiano	4	0	0	0	1	0	0	0.17
Boretto	5	0	0	0	0	0	0	0
Brescello	6	0	0	0	0	0	0	0
Busana	7	0	1	0	1	0	0	0.33
Cadelbosco sopra	8	0	0	0	0	0	0	0
Campagnola	9	0	0	1	0	0	1	0.33
Campegine	10	0	1	0	0	0	0	0.17
Canossa	11	0	0	0	0	0	0	0
Carpineti	12	1	0	0	0	0	0	0.17
Casalgrande	13	0	0	0	0	1	1	0.33
Casina	14	1	0	0	0	0	0	0.17
Castellarano	15	0	0	0	1	1	1	0.50
Castelnovo sotto	16	0	0	0	0	0	0	0
Castelnovo monti	17	0	0	0	0	0	0	0
Cavriago	18	0	0	1	0	1	0	0.33
Collagna	19	1	1	0	1	0	0	0.50
Correggio	20	0	0	1	0	1	0	0.33
Fabbrico	21	0	1	1	0	0	0	0.33
Gattatico	22	0	0	1	1	1	0	0.50
Gualtieri	23	0	1	1	0	0	0	0.33
Guastalla	24	0	0	0	0	0	0	0
Ligonchio	25	1	0	0	1	0	0	0.33
Luzzara	26	0	0	0	0	0	0	0
Montecchio Em.	27	0	0	0	0	1	0	0.17
Novellara	28	0	1	0	0	0	0	0.17
Poviglio	29	0	1	0	0	0	0	0.17
Quattro Castella	30	0	0	0	0	0	1	0.17
Ramiseto	31	1	1	0	0	0	0	0.33
Reggio Emilia	32	0	0	0	0	0	0	0
Reggiolo	33	0	1	0	1	0	0	0.33
Rio Salicieto	34	0	0	0	0	0	1	0.17
Rolo	35	0	0	1	1	0	1	0.50
Rubiera	36	0	0	0	0	1	1	0.33
S.Martino in Rio	37	0	0	0	1	0	1	0.33
S.Polo d'Enza	38	0	0	0	0	0	0	0
S.Ilario d'Enza	39	0	0	1	0	1	0	0.33
Scandiano	40	0	0	0	0	0	0	0
Toano	41	0	0	0	0	0	0	0
Vetto d'Enza	42	1	0	0	0	0	0	0.17
Vezzano sul Cr.	43	0	0	0	0	0	0	0
Viano	44	1	0	0	0	0	0	0.17
Villa Minozzo	45	1	0	0	0	0	0	0.17

result suggested that this parameter is not a strict indicator of response.

Economic performance is well represented by the first component, which explains 78% of the total variance (Table 6). Because both I15 and I16 show a positive correlation with this component, it is interpreted as an index of economic well-being. Municipalities score as expected: Economy thrives where industrial

Table 9. Grade of membership of each municipality in the fuzzy set called "bad performance"

Municipality	ID.	Settlement pressure Z1	Industrial pressure Z2	Incapability for response Z3	Environmental expenditure Z4	Economic well being Z5	Unbalanced population Z6	μA
Albinea	1	0	0	0	0	0	0	0
Bagnolo in Piano	2	0	0	0	1	0	0	0.17
Baiso	3	0	0	1	1	1	0	0.50
Bibbiano	4	1	0	0	0	0	0	0.17
Boretto	5	0	0	0	0	0	0	0
Brescello	6	0	0	0	0	0	0	0
Busana	7	0	0	0	0	0	0	0
Cadelbosco sopra	8	0	0	0	0	0	0	0
Campagnola	9	0	0	0	1	0	0	0.17
Campegine	10	1	0	0	0	0	0	0.17
Canossa	11	0	1	1	1	1	1	0.83
Carpineti	12	0	0	1	0	1	1	0.50
Casalgrande	13	0	1	0	1	0	0	0.33
Casina	14	0	0	0	0	1	0	0.17
Castellarano	15	0	1	0	0	0	0	0.17
Castelnovo sotto	16	0	0	0	0	0	0	0
Castelnovo monti	17	0	0	0	0	0	1	0.17
Cavriago	18	1	1	0	1	0	0	0.50
Collagna	19	0	0	0	0	0	1	0.17
Correggio	20	0	1	0	0	0	0	0.17
Fabbrico	21	0	0	0	0	0	0	0
Gattatico	22	0	0	0	0	0	0	0
Gualtieri	23	0	0	0	0	0	0	0
Guastalla	24	0	0	0	0	0	1	0.17
Ligonchio	25	0	0	1	0	0	1	0.33
Luzzara	26	0	0	0	0	0	0	0
Montecchio Em.	27	1	0	0	0	0	0	0.17
Novellara	28	1	0	0	0	0	0	0.17
Poviglio	29	0	0	0	1	0	0	0.17
Quattro Castella	30	0	0	0	0	0	0	0
Ramiseto	31	0	0	1	0	1	1	0.50
Reggio Emilia	32	1	0	0	0	0	0	0.17
Reggiolo	33	1	0	0	0	0	0	0.17
Rio Salicieto	34	0	1	0	0	0	0	0.17
Rolo	35	0	0	0	0	0	0	0
Rubiera	36	1	1	0	0	0	0	0.33
S.Martino in Rio	37	0	1	0	0	0	0	0.17
S.Polo d'Enza	38	0	0	0	0	0	0	0
S.Ilario d'Enza	39	0	0	0	0	0	0	0
Scandiano	40	1	0	0	0	0	0	0.17
Toano	41	0	0	1	1	1	0	0.50
Vetto d'Enza	42	0	0	1	1	1	1	0.67
Vezzano sul Cr.	43	0	0	0	0	1	0	0.17
Viano	44	0	1	1	0	0	0	0.33
Villa Minozzo	45	0	0	1	0	1	1	0.50

activities concentrate, whereas mountainous areas are economically less developed (Figure 4b).

One component explains 85% of the total variance of social indicators. Age index and net migration behave in opposite ways with respect to this emerging dimension, which can be considered an index of unbalanced population. In fact, it correlates positively with age index and negatively with net migration. Its

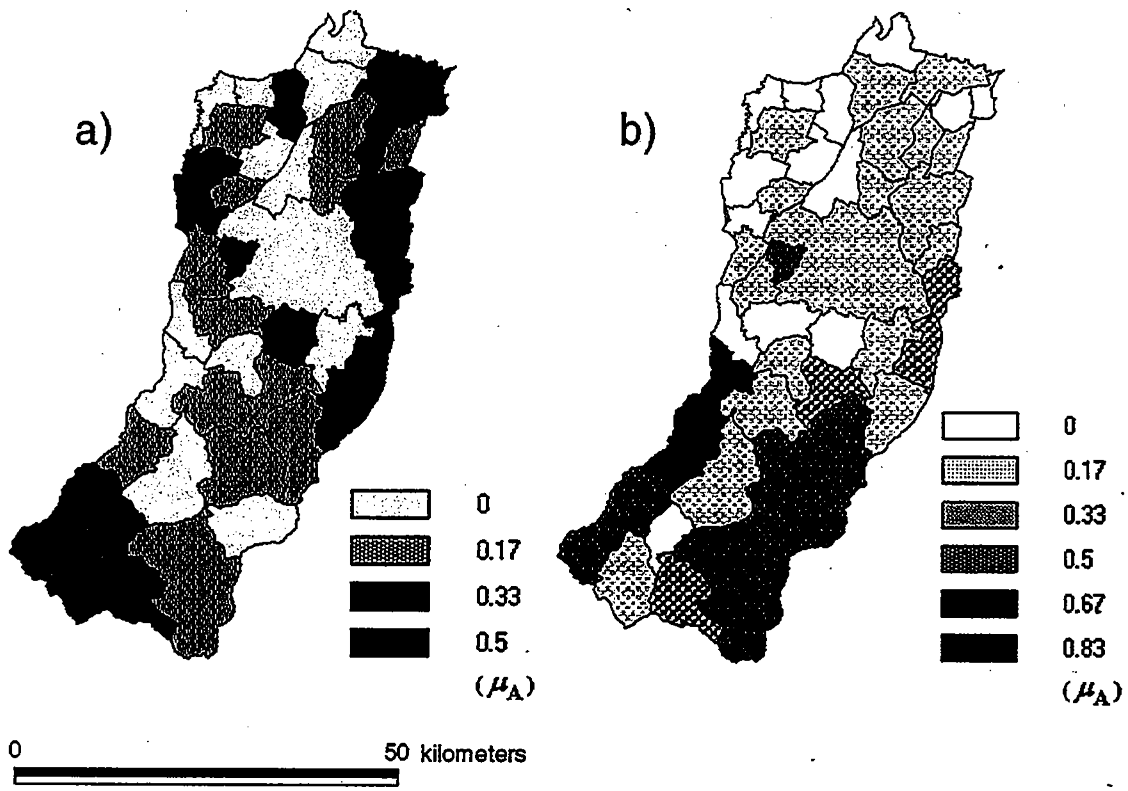


Figure 5. Maps representing for each municipality the grade of membership to the fuzzy set of good environmental performance (a) and bad environmental performance (b).

spatial distribution (Figure 4c) reveals a clear polarization toward mountainous areas, where populations are not balanced and show high emigration values (Ferrarini and others 2001).

Municipal performance in relation to the six fundamental dimensions was taken to build an index of environmental performance using fuzzy sets. To be part of the fuzzy set "good performance," each municipality had to meet the following condition (rule of membership):

$$\left(\begin{array}{l}\text{Low}\\ \text{environmental}\\ \text{pressure}\end{array}\right) \textit{and} \left(\begin{array}{l}\text{Low}\\ \text{industrial}\\ \text{pressure}\end{array}\right) \textit{and} \left(\begin{array}{l}\text{Low}\\ \text{incapabilty}\\ \text{forresponse}\end{array}\right) \textit{and} \left(\begin{array}{l}\text{High}\\ \text{environmental}\\ \text{expenditure}\end{array}\right) \textit{and} \left(\begin{array}{c}\text{High economic}\\ \text{well-being}\end{array}\right) \textit{and} \left(\begin{array}{l}\text{Low}\\ \text{population}\\ \text{unbalance}\end{array}\right)$$

in which "low" and "high" mean scoring in the top 20% with respect to the six principal components. The same rule applies for the fuzzy set called "bad performance," where scoring in the bottom 20% of every dimension would assign a municipality a complete membership to that fuzzy set.

Table 8 summarizes the grade of membership for each municipality in the fuzzy set of good performance; Table 9 shows the grade of membership in the fuzzy set of bad performance. Maps in Figure 5 summarize the results of Tables 8 and 9.

As shown in Figure 5b, municipalities with high grade of membership for the fuzzy set of bad performance are prevalently those in the southern part of the province (mountain district). This means that for the majority of the conditions that make up the rule of membership for the former fuzzy sets (see Methods section), municipalities of the mountain district are concentrated in the first 20%. Although, in general, mountainous areas show very good environmental quality (low settlement pressure and low industrial pressure), they perform poorly in terms of economic

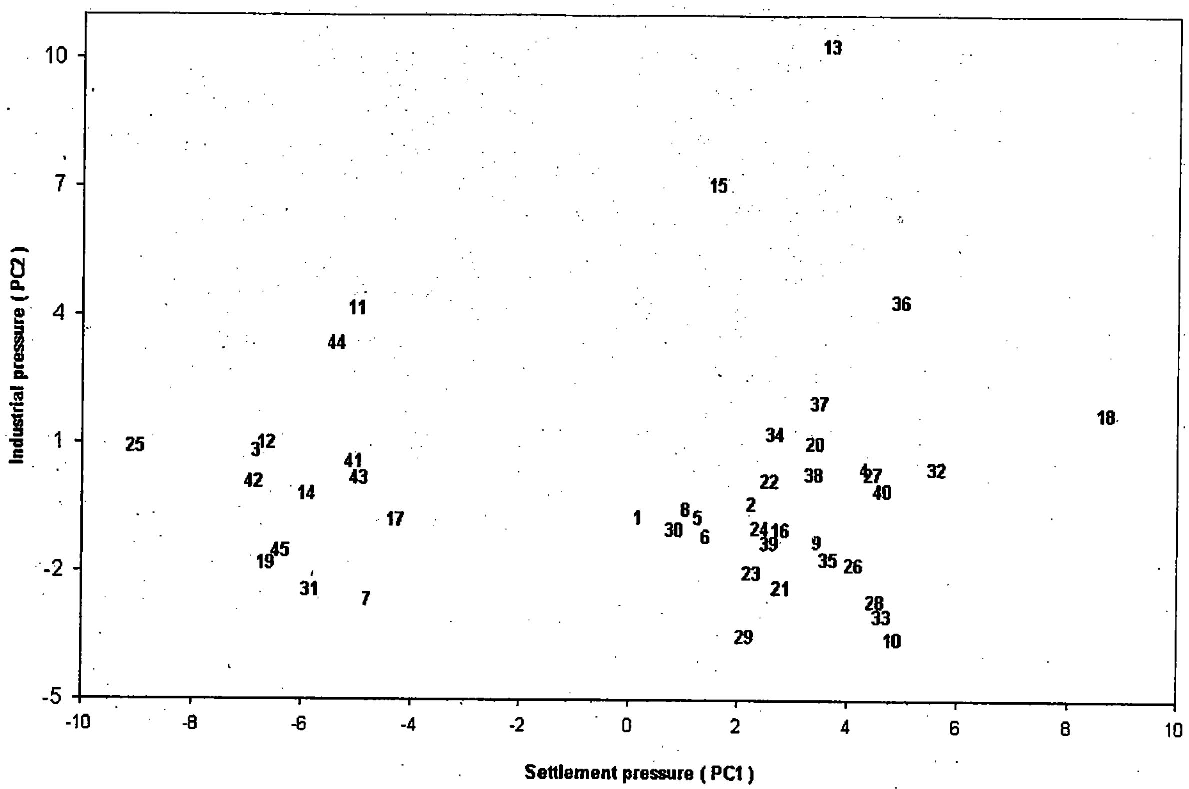


Figure 6. Scatterplot of the principal components scores representing industrial pressure and settlement pressure. Numbers represent municipality identifiers.

welfare, environmental expenditure, response capability, and population structure. For the "good performance" fuzzy set (Figure 5a), on the contrary, municipalities that score in the top 20% change from one dimension to another, and good environmental performance is widespread in the whole province. The four municipalities with the best score (0.50) are located in the mountain district (M19), in the hilly part of the province (M15), and in the lowlands (M22 and M35).

Discussion

Various groups are involved in the environmental quality debate: members of the public, who need to know the state of the environment in which they live; policy-makers, who are responsible for environmental policies at the different layers of the administrative hierarchy; and scientists, who must produce knowledge and operative tools to improve environmental conditions. These various stakeholders require different levels of detail of environmental information. Accordingly, the information system should be organized into hierarchies of increased scale and decreasing specificity (EUROSTAT 1999). In this study, the hierarchical structure of information was obtained by progressive aggregation of the initial suite of metrics using Pearson's correlation, principal component analysis, and fuzzy sets.

Any index or indicator system that is intended to communicate trends to nonexperts must use the public's language (Meadows 1998). The aggregated index obtained using fuzzy sets meets this requirement, by condensing the original information into two broad and simple categories: good and bad performances. Perhaps these two categories are rather vague: Immediately, one would raise an inquiry about what is meant by good and bad performances. The problem here does not concern as much the methodology *per se*, as the initial list of indicators: If consensus on which metrics should be used to monitor environmental conditions at all scales were reached, certainly the meaning of bad and good performances would be less uncertain.

On the other hand, the meaning of each of the six dimensions in which the bulk of the information converged after principal component analysis is certainly less ambiguous than simple "bad" and "good" attributes. However, terms such as environmental pressure, environmental response, or population unbalance might not be comprehensible to members of the public, and further aggregation is needed to create a more understandable index. Compression had to deal somehow with the imprecision of the judgment associated with the six new dimensions of environmental quality, for which absolute scales do not exist. Fuzzy sets, as specifically designed to treat uncertainty and ambiguity, appeared appropriate to aggregate the information into few, easily interpretable categories of environmental quality (Carlsson and Fuller 1996; Dubois and others 1997).

In addition to providing municipal performance information and what is most relevant to citizen and municipal administrators, the structure of the two fuzzy sets reveals also an interesting pattern at the provincial scale. The bad performance index shows a rather clear spatial distribution, whereas good performance appears more equally spread across the province. Best scores for good quality are all equal to 0.5, which means that all of these municipalities perform well in three out of the six dimensions of environmental quality (see Table 9). Results of the correlation and PCA showed that where the physical environment is well preserved, the economy tends to be depressed and the population strongly unbalanced in favor of old age classes. These conditions are typical of mountainous areas. The opposite occurs in lowland municipalities: There, the economy thrives and the population is well balanced, but the physical environment suffers the consequences of heavy human pressure. Because two of the aggregated dimensions pertain to socio-economic issues, two relate to the physical environment and the last two concern administrative policies—municipalities of both mountain and lowlands districts that took action in some way (either they increased environmental expenditure or responded to specific problems) automatically entered the best 20% results of the good-quality fuzzy set. Thus, best performances in the whole province hide a medium-to-low environmental quality in absolute terms.

In the bad-performance fuzzy set, the highest scores reach a maximum of 0.83, a sign that scarce quality reaches very high levels (i.e., it embraces five of the six dimensions of environmental quality). This means that some municipalities in the mountainous areas are eroding their natural capital without reaching good results on the socio-economic side. Because of historically low environmental pressure, they are not prepared to tackle environmental problems posed by present and future economic development; thus, their response capability remains low. This tendency, if confirmed by further investigation, will pose serious problems to the provincial administration as well as the single municipalities of the mountain district.

In general, policies are targeted to specific sectors of human activity and they are conceived using single indicators or groups of more or less homogeneous measures as reference system (Bossel 1999). In this light, the need for aggregation remains of minor importance and using the original set of indicators would be appropriate. In fact, it would be difficult for any manager to deduce what pollutant or attribute needs to be altered to improve the environment starting from the fuzzy sets that describe broad categories. This issue reflects entirely the major controversy about index development, which stems from two views. One holds that raw data give the best means of evaluating environmental conditions, whereas the other view states that raw data are too complex and that a simplification process is necessary even if there is a potential loss of information (Meadows 1998).

However, sustainability applies to human systems in their wholeness (Kelly 1998). When results of different policies are conflicting, monitoring progress toward sustainability is not possible unless the single measures are framed in the context of the whole system. This has been done here in two steps. The intermediate level of aggregation not only retained essential information from the initial suite of metrics and provided manageable indices to build fuzzy sets but also clarified some results of the correlation analysis. This aggregation provided new synthetic knowledge of patterns at the provincial scale, which otherwise might not have been obvious in the single measures. The complex network of relationships between indicators highlighted by the correlation matrix hides two distinct dimensions of environmental pressure that clearly emerge from the principal components: one due to settlements (civil and agricultural) and the other due to industrial activities. The spatial distribution of the two new dimensions (Figure 3a and 3b) can be further appreciated in Figure 6, which plots the two dimensions of environmental pressure against one another.

Figure 6 confirms that municipalities are split into two well-defined groups with respect to settlement pressure, whereas industrial pressure reflects only partially in this pattern. Municipalities in which industrial pressure is strong are M13, M15, M36, M11, and M44. With the exception of M11, they all belong to the area of ceramic tile production, a district that strongly affects the spatial distribution of industrial pressure and economic welfare (see Figure 4b).

Remarkable progress has been obtained in promoting the idea of sustainability and its practical issues by organizing environmental statistics into frameworks. This helps to understand cause-and-effect relationships, providing a more dynamic use of environmental indicators. Examples of these frameworks are the Pressure-State-Response (PSR) and the Driving force-Pressure-State-Impact-Response (DPSIR) models (Stunners and Bordeau 1995). The possibility of obtaining more aggregated metrics for each group of indicators specified in either model might be extremely useful to policy-makers who need to organize their political action in a more efficient way. This could avoid being flooded with detailed information concerning single measures while providing a dynamic view of the environment. Questions such as "What is the overall level of pressure on the environment of a certain area?" or "What are the patterns of response?" might become more relevant for summarizing in a coherent fashion all the critical issues pertaining to environmental policies at the various levels of governance. In this article, these issues have not been considered in full; however, principal component analysis, through which synthetic measures of pressure and response have been obtained, demonstrates its potential in this respect. To apply PSR and DPSIR models to the specific context described in the present study, further metrics should be added to the list of Table 1. In fact, all of the various categories that comprise the two models must be adequately represented. This could not be done with the information available because small municipalities often lack the economic and human resources to gather such data. More specifically in this context, attention must be paid to the issue of local inclusion. In other words, further refinement of the indicators list should be done through a validation procedure involving local people, because previous studies have recognized that the indicator selection process works best with a combination of expert and grassroots participation (Meadows 1998).

Conclusions

In complex political debates about the environment, the use of highly aggregated indices is necessary to communicate the most relevant information to understand overall patterns and use them to support decisions. This process involves the various levels of governance as well as the public opinion through their decisions. Because stakeholders possess different skills, the same information has to be disseminated using different means. In this article, information about baseline environmental conditions in 45 municipalities of the Reggio Emilia province has been progressively aggregated. Principal component analysis provided a first synthesis and highlighted patterns of pressure on the environment, level of response, economic welfare, and population status at the provincial scale. In turn, these indications have been summarized in two more aggregated indices of bad and good performance, more adapted to meet the requirements of members of the public. Through this exercise, we also showed that no complete comprehension of environmental quality is possible only by focusing at a specific layer of the information hierarchy. Only through an integrated view of all these levels can progress be achieved in selecting the most efficient indicators, identifying tools for summarizing essential information and using it for practical purposes. Although aware of the limitations of this study, we believe that even a modestly successful effort by presenting a series of aggregated indices could help to introduce a generation of policy-makers and decision-makers to the goals of sustainable development.

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